FORM 2

THE PATENTS ACT, 1970

(39 of 1970)

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The Patent Rules, 2003

COMPLETE SPECIFICATION

(See sections 10 & rule 13)

1. TITLE OF THE INVENTION

DUAL-LEVER RIGIDISATION MECHANISM WITH A SELF-HOLD DOWN FEATURE FOR AUTONOMOUS DOCKING OF SPACECRAFT

2. APPLICANT (S)

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3. PREAMBLE TO THE DESCRIPTION

COMPLETE SPECIFICATION

The following specification particularly describes the invention and the manner in which it is to be performed.

TECHNICAL FIELD

[0001] The present disclosure relates, in general, to a spacecraft docking, and more specifically, relates to a dual-lever rigidisation mechanism with a self-hold down feature for autonomous docking of spacecraft.

BACKGROUND

[0002] International Berthing and Docking Mechanism (IBDM) developed by other space agencies constitutes a hard docking system, which makes the structural pressurized connection between the two spacecrafts and is responsible for the service connections and the nominal and emergency separation functions. The existing structure 100 of IBDM is disclosed in FIG. 1. Post retraction, a series of latches are engaged which establish a structural connection between the IBDM and the vehicle. Each IBDM includes 12 latches that are attached in a tangential direction to the outside of the tunnel wall shown in FIG. 1. Each latch has its proper motor, gearbox, and adjustable compliance element. The motor and the gearbox are developed as an integrated actuator unit. Dual failure tolerance has been established for both docking and undocking, and the inherent positive locking of the mechanism provides the guarantee against inadvertent release. The redundancy in the latch release is accomplished by a primary and a secondary drive, plus a pyrotechnic solution. The latch secondary drive consists of tilting the latch hook by rupturing the hold-down bolt with a Frangibolt actuator or with a rich bolt cutter (pyrotechnic). This concludes that the hard latch system comprises twelve main and twelve redundant motor drives i.e., a total of 24 in addition to 12 pyrotechnics for individual latches.

[0003] The hard latch system developed by other space agencies constitutes 24 motor drives and 12 pyrotechnics for individual latches. This adds to additional mass, and launch cost and reduces the reliability of the overall system due to additional moving components and electrical complexity to power above actuators. This system is utilized presently for docking of Automated Transfer Vehicle (ATV) with the mass of the order of 21 tons with the 400 ton ISS i.e. large inertia-based systems.

[0004] Therefore, it is desired to overcome the drawbacks, shortcomings, and limitations associated with existing solutions, and develop a cost-effective mechanism that performs critical operations by ingenious usage of a single mechanism, actuated using a single motorized actuator thereby saving mass, enhancing reliability, amplifying the output torque and reduced launch cost.

OBJECTS OF THE PRESENT DISCLOSURE

[0005] An object of the present disclosure relates, to a spacecraft docking, and more specifically, relates to a dual lever rigidisation mechanism with a self-hold down feature for autonomous docking of spacecraft.

[0006] Another object of the present disclosure is to provide a system that performs two vital functions i.e., hold down during launch and imparts requisite preload to achieve adequate composite stiffness for controlling both spacecraft together as a single body post docking.

[0007] Another object of the present disclosure is to provide a system that avoids three additional hold-down mechanisms and helps in the design of a compact actuator.

[0008] Yet another object of the present disclosure is to provide a system that performs critical operations by ingenious usage of a single mechanism, actuated using a single motorized actuator thereby saving mass, enhancing reliability, amplifying the output torque, and reducing launch cost.

SUMMARY

[0009] The present disclosure relates, in general, to spacecraft docking, and more specifically, relates to a dual lever rigidisation mechanism with a self-hold down feature for autonomous docking of two spacecraft. The main objective of the present disclosure is to overcome the drawback, limitations, and shortcomings of the existing system and solution, by providing a system having a dual lever rigidisation mechanism to perform hold down mechanism during launch and rigidization mechanism post docking of the two spacecraft actuated using a single motorized actuator.

[0010] The present disclosure relates to a system for docking a chaser vehicle to a target vehicle. The system includes a rigidization mechanism configured in the chaser vehicle and the target vehicle. The rigidization mechanism having at least three levers spaced equally located at the periphery of the housing of the chaser vehicle and the target vehicle, each lever having a primary lever in a vertical position and a secondary lever in a horizontal position. The primary lever can include a first wedge profile located at the top portion defining a rigidization interface, the rigidization interface adapted to rigidize, upon docking, the chaser vehicle and target vehicle together and a second wedge profile located at the middle portion defining a launch interface, the launch interface adapted to hold deploying appendages in stowed position during launch. Thus, the dual lever rigidisation mechanism with a self-hold down feature for autonomous docking of two small spacecraft capable of performing two vital functions i.e., hold down during launch and imparts requisite preload to achieve adequate composite stiffness for controlling both spacecraft together as a single body post docking. The mechanism avoids an additional hold down and release mechanism for holding the capture ring during the launch.

[0011] A guide pulley is configured in the secondary lever, the guide pulley is adapted to guide a wire rope loop. The wire rope loop is adapted to connect at least three levers together. A motorized actuator coupled to the guide pulley through the wire rope loop, the motorized actuator, upon operation, is adapted to drive at least three levers to facilitate release, hold down and rigidize operations. The use of a single cable or rope minimizes the requirement of number of motors. Thus, the three compound lever assemblies are constrained in the held down position by the usage of the single wire loop connected to the drive pulley using a non-back drivable actuator thereby avoiding three additional hold down mechanisms and helping in the design of the compact actuator.

[0012] Further, the rigidization mechanism can include a strain gauge located on the primary lever, the strain gauge adapted to monitor the rigidisation preload. The at least three levers comprise three leaf spring-based switches that comprise rigidisation switch for rigidised operation, a launch switch for hold

down operation and a release switch for release operation indication. The leaf springs with two flexible strips arranged in different planes establish positive electrical contact between mating parts in case of misalignment and are ingeniously profiled in a curved fashion to resist against the launch acceleration loads.

[0013] Those skilled in the art would appreciate that as the critical operations are performed by ingenious usage of a single mechanism, actuated using a single motorized actuator in the present invention, the additional material usage and additional assembly operation may not be required, thereby saving mass, enhances reliability, amplifying the output torque and reduces launch cost. In addition, leaf springs are ingeniously profiled in a curved fashion to resist the launch acceleration loads.

[0014] Various objects, features, aspects, and advantages of the inventive subject matter will become more apparent from the following detailed description of preferred embodiments, along with the accompanying drawing figures in which like numerals represent like components.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The following drawings form part of the present specification and are included to further illustrate aspects of the present disclosure. The disclosure may be better understood by reference to the drawings in combination with the detailed description of the specific embodiments presented herein.

[0016] FIG. 1 illustrates an exemplary schematic view of international berthing hand docking mechanism, in accordance with an embodiment of the present disclosure

[0017] FIG. 2A illustrates an exemplary satellite in proximity, in accordance with an embodiment of the present disclosure.

[0018] FIG. 2B illustrates an exemplary satellite in docket configuration, in accordance with an embodiment of the present disclosure.

[0019] FIG. 2C illustrates an exemplary schematic view of rigidisation mechanism, in accordance with an embodiment of the present disclosure.

[0020] FIG. 2D illustrates an exemplary exploded view of the rigidization mechanism, in accordance with an embodiment of the present disclosure.

[0021] FIG. 2E illustrates a schematic view of the docking mechanism in the launch and rigidised configuration, in accordance with an embodiment of the present disclosure.

[0022] FIG. 3A illustrates a schematic view of the compound lever mechanism, in accordance with an embodiment of the present disclosure.

[0023] FIG. 3B illustrates a schematic view of the indication switch with location on the lever, in accordance with an embodiment of the present disclosure.

[0024] FIG. 3C illustrates a schematic on board monitoring of rigidisation preload using strain gauges, in accordance with an embodiment of the present disclosure.

[0025] FIG. 4A to 4B illustrate realized hardware of rigidization mechanism held down and released configuration, in accordance with an embodiment of the present disclosure.

[0026] FIG. 5A illustrates a schematic view of the worm and worm wheel-based spool mechanism, in accordance with an embodiment of the present disclosure.

[0027] FIG. 5B illustrates a cross-sectional worm and worm wheel-based spool mechanism, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0028] The following is a detailed description of embodiments of the disclosure depicted in the accompanying drawings. The embodiments are in such detail as to clearly communicate the disclosure. If the specification states a component or feature “may”, “can”, “could”, or “might” be included or have a characteristic, that particular component or feature is not required to be included or have the characteristic.

[0029] As used in the description herein and throughout the claims that follow, the meaning of “a,” “an,” and “the” includes plural reference unless the context clearly dictates otherwise. Also, as used in the description herein, the

meaning of “in” includes “in” and “on” unless the context clearly dictates otherwise.

[0030] The present disclosure relates, in general, to a spacecraft docking, and more specifically, relates to a dual lever mechanism with a self-hold down feature for autonomous docking of spacecraft. The proposed system disclosed in the present disclosure overcomes the drawbacks, shortcomings, and limitations associated with the conventional system providing a dual lever rigidisation mechanism that can be used for large as well as low inertia-based spacecraft as the concept can be scaled up suitably to meet docking requirements. The mechanism is mass and power optimised and reduces launch cost as it uses a single motorised actuator connecting all three levers connected through a tensioned wire loop system for motion transfer. The present disclosure can be described in enabling detail in the following examples, which may represent more than one embodiment of the present disclosure.

[0031] The proposed mechanism serves as a technology demonstrator for Indian Space Docking Experiment planned to be carried out on two 200Kg class spacecraft viz. chaser and target, with optimised resources like mass, power, and space. The design of rigidisation mechanism is carried out using the concept of a compliant compound lever system, which enhances mechanical advantage at output thereby minimising the actuator torque requirements and subsequently saving mass. The rigidisation mechanism should act as a hold down during launch and rigidize the target interface ring with the chaser interface ring to achieve requisite composite stiffness. Moreover, the mechanism should not have any consumables and should be repeatable for multiple docking attempts using a single actuator. This concept may be useful for future docking mechanisms involving crew transfer onboard the Indian space station.

[0032] The advantages achieved by the mechanism of the present disclosure can be clear from the embodiments provided herein. The mechanism has a minimum number of components thereby enhancing its reliability of the mechanism. The position indication is provided using a contact switch-based telemetry system. The proposed mechanism saves additional actuators and hold

down mechanism mass of more than three Kgs per docking mechanism as compared to conventional systems, which amounts to a large cost per spacecraft launch budget. The mass saved may be utilised for the accommodation of an additional payload on spacecraft. The rigidisation mechanism acts as a hold down during launch by providing the requisite clamping force to the capture ring and the extension/retraction mechanism as there is no separate hold down mechanism planned to sustain launch loads. This is achieved by ingenious usage of the self-locking property of worm and worm gears, which thereby reduces complexity and helps in the design of compact actuator by amplifying the output torque. The mechanism provides sufficient rigidisation preload to clamp the target interface ring with the chaser interface ring thereby providing requisite composite stiffness after the chaser spacecraft captures and retracts the target spacecraft in orbit. Both the operations are performed by ingenious usage of a dual lever mechanism actuated using a single motorized actuator and capable of performing repeatable operations on the ground and in space. The description of terms and features related to the present disclosure shall be clear from the embodiments that are illustrated and described; however, the invention is not limited to these embodiments only. Numerous modifications, changes, variations, substitutions, and equivalents of the embodiments are possible within the scope of the present disclosure. Additionally, the invention can include other embodiments that are within the scope of the claims but are not described in detail with respect to the following description.

[0033] FIG. 2A illustrates an exemplary satellite in proximity, in accordance with an embodiment of the present disclosure.

[0034] Referring to FIG. 2A, autonomous vehicle docking system 200 (also referred to as system 200, herein) provides for docking two small spacecraft in orbit. The two small spacecraft can include a chaser vehicle 202-1 and a target vehicle 202-2. The chaser vehicle 202-1 is adapted to perform the capture or servicing operations, and the target vehicle 202-2 is adapted to be captured or serviced. The chaser and target vehicles (202-1, 202-2), for example, can be spacecraft is illustrated in proximity to one another prior to docking in FIG. 2A.

The docket configuration of the chaser and target vehicles (202-1, 202-2) is shown in FIG. 2B.

[0035] The two small spacecraft of 200Kg class, the chaser vehicle 202-1 (also referred to as chaser 202-1) and target vehicle 202-2 (also referred to as target 202-2) may be rendezvous after ejection from the launcher interface in orbit and then come in proximity. The chaser vehicle 202-1 approaches the target vehicle 202-2 with low relative velocity using closed-loop guidance with rendezvous and docking sensors in the loop. Once the spacecraft approaches the capture envelope, the capture mechanism in the chaser vehicle 202-1 can actuate to capture the target vehicle 202-2. Once the disturbances settle down, the extension/retraction mechanism can retract the target vehicle 202-2 and then rigidisation mechanism 204 shown in FIG. 2C can impart requisite preload to achieve adequate composite stiffness for controlling both vehicles (202-1, 202-2) together as a single body. A peripheral arrangement of the docking mechanism is adopted as the central port is available for post-docking operations. A similar configuration of docking mechanism is provided in chaser vehicle 202-1 and target vehicle 202-2 for redundancy and makes the system androgynous.

[0036] FIG. 2C illustrates an exemplary schematic view of rigidisation mechanism, in accordance with an embodiment of the present disclosure. Referring to FIG. 2C, the rigidisation mechanism 204 configured in both the chaser vehicle 202-1 and target vehicle 202-2 are configured to perform two vital functions i.e., it can act as a hold down during launch and imparts requisite preload to achieve adequate composite stiffness for controlling both vehicles (202-1, 202-2) together as a single body post docking. The docking mechanism is active in the chaser vehicle 202-1 and passive in the target vehicle 202-2. In case of any contingency in orbit, the target vehicle 202-2 can be made active to perform the required functions.

[0037] The proposed mechanism 204 serves as a technology demonstrator for Indian Space Docking Experiment planned to be carried out on two 200Kg class spacecrafts, chaser and target, with optimised resources like mass, power and space. The design of rigidisation mechanism 204 is carried out using a

concept of compliant compound lever system, which enhances mechanical advantage at output thereby minimising the actuator torque requirements and subsequently saving mass. The rigidisation mechanism 204 acts as a hold down during launch and rigidize the target interface ring with the chaser interface ring to achieve requisite composite stiffness. Moreover, mechanism 204 should not have any consumable and should be repeatable for multiple docking attempts using a single actuator. This concept may be useful for future docking mechanisms involving crew transfer onboard Indian Space Station.

[0038] FIG. 2D illustrates an exemplary exploded view of the rigidisation mechanism, in accordance with an embodiment of the present disclosure. The rigidisation mechanism 204 can include rigidisation levers (206-1 to 206-3 (which are collectively referred to as levers 206, herein)), lever hinge 208, guide pulleys 210, torsion spring 212, continuous wire rope loop 214, loop end assembly 216, loaded hard stopper 218, unloaded hard stopper 220, an actuator 222 and connector 228.

[0039] In an exemplary embodiment, the rigidisation mechanism 204 having atleast three levers 206 spaced equally located at the periphery of the housing of the chaser vehicle 202-1 and the target vehicle 202-2, each lever 206 having a primary lever 302-1 in the vertical position and a secondary lever 302-2 in the horizontal position shown in FIG. 3A.

[0040] The primary lever 302-1 can include a first wedge profile 224-1 and a second wedge profile 224-2. The first wedge profile 224-1 is located at the top portion defining a rigidisation interface, the rigidisation interface is adapted to rigidize, upon docking, the chaser vehicle 202-1 and target vehicle 202-2 together. The second wedge profile 224-2 is located at a middle portion defining a launch interface, the launch interface adapted to hold deploying appendages in stowed position during launch.

[0041] The guide pulley 210 is configured in the secondary lever 302-2, where the guide pulley 210 is adapted to guide the wire rope loop 214, and the wire rope loop 214 is adapted to connect the at least three levers 206 together. The motorized actuator 222 coupled to the guide pulley 210 through the wire rope loop

214, the motorized actuator 222, upon operation, adapted to drive at least three levers 206 to facilitate release, hold down and rigidize operations, thereby avoiding individual three actuators and multiple motors to perform the required operations. In an exemplary embodiment, the motorized actuator 222 is a non-back drivable actuator, where the non-back drivable actuator is a worm and worm gear-based drive mechanism. The worm and worm gear-based drive mechanism 222 avoids the back drive of the system 200 and amplifies the torque of the system. The worm and worm gear-based drive mechanism 222 helps in retaining tension in the wire rope loop thereby maintaining requisite preload against launch acceleration.

[0042] The motorized actuator 222 drives at least three levers 206 to perform hold-down operations during launch by providing the requisite clamping force to hold the capture ring 226 shown in FIG. 2E of the chaser vehicle 202-1. The motorized actuator 222 drives at least three levers 206 to perform rigidize operations by providing suitable preload to provide adequate composite stiffness for controlling both the chaser vehicle 202-1 and target vehicle 202-2 together. The motorized actuator 222 drives at least three levers 206 to perform release operations by releasing the capture ring 226 of the chaser vehicle 202-1.

[0043] Further, the loaded hard stopper 218 and unloaded hard stopper 220 can be adapted to limit extreme movements of levers 206.The lever 206 can rotate at the lever hinge 208. The torsion spring 212 is a helical spring that exerts a torque or rotary force adapted to provide the necessary torque to deploy the levers 206. The torsion spring 212 is coupled to the levers 206 through a mounting bracket 304 shown in FIG. 3A

[0044] The rigidisation mechanism 204 is carried out using the concept of a compliant compound lever system, which enhances mechanical advantage at output thereby minimising the actuator torque requirements and subsequently saving mass. The rigidisation levers 206 apply the necessary preload at a suitable interface through tensioned SS wire rope 214 connecting all the three rigidisation levers 206 together. The motion in levers 206 is transferred through pulleys 210

and rope 214. The use of a single cable or rope 214 minimizes the number of motors.

[0045] Further, mechanism 204 is modular in nature which reduces dependability on other subsystems during assembly and testing. In addition, the mechanism has provision for a novel contact switch-based telemetry indication for launch, release and rigidised position shown in FIG 3B. The rigidisation levers 206 have a provision for on-orbit preload monitoring using strain gauges 334. The levers 206 are configured to avoid any interference between other mechanical elements during docking.

[0046] FIG. 2E illustrates a schematic view of the docking mechanism in the launch and rigidised configuration, in accordance with an embodiment of the present disclosure. The rigidisation mechanism 204 can include rigidisation levers 206. Each rigidisation levers 206 can include a suitable wedge which helps in self-release. Each lever 206 can include the first wedge profile 224-1 at the top portion of the lever 206 for rigidisation interface (I/F) and the second wedge profile 224-2 at the middle portion of the lever 206 for launch interface (I/F).

[0047] The rigidisation mechanism 204 acts as a hold down during launch configuration by providing the requisite clamping force to the capture ring and the extension/retraction mechanism as there is no separate hold down mechanism planned to sustain launch loads. This is achieved by ingenious usage of the self-locking property of worm and worm gears, which thereby reduces complexity and helps in the design of compact actuator by amplifying the output torque.

[0048] The rigidisation levers 206 rigidizes the target interface ring with the chaser interface ring with a necessary preload after chaser vehicle 202-1 or spacecraft captures and retracts the target vehicle or spacecraft 202-2 in orbit. The launch configuration and rigidized configuration are performed by ingenious usage of the dual lever mechanism 206 actuated using the single motorized actuator 222 and repeatable operations can be carried out on the ground and in space.

[0049] FIG. 3A illustrates a schematic view of the compound lever mechanism, in accordance with an embodiment of the present disclosure. The

lever mechanism 206 can include the primary lever 302-1 in the vertical configuration and the secondary lever 302-2 in the horizontal configuration. The torsion spring 212 is coupled to the primary lever 302-1 through the mounting bracket 304. The guide pulleys 210are in the secondary lever 302-2, the guide pulleys 210 are adapted to route the wire rope loop 214 within the given space. A lock nut 306 coupled to the guide pulleys 210 to resist loosening under vibration and torque. Further, a spring anchor 308 and spring post 310 are coupled to the lever 206.

[0050] The spacer such as Delrin spacer 314 must be able to effectively withstand considerable pressure, wear, torque, friction, and abrasive conditions, while maintaining the shape and functionality of the mechanism during launch configuration. The glass fiber reinforced polymer (GFRP) spacer 312 is located on the top portion of lever 206, the GFRP spacer 312 provides electromagnetic shielding and isolates the lever body from the current. Further, the lever mechanism can include shaft 316, spring adaptor 318, DU bush 320 and mandrel 322.

[0051] FIG. 3B illustrates a schematic view of indication switch 300 with location on the lever, in accordance with an embodiment of the present disclosure. The rigidisation mechanism 204 can include a provision for a contact switch-based telemetry indication for launch, release and rigidised position as shown in FIG. 3B. The rigidisation lever 206 can include a provision for three leaf spring-based switches located on the lever 206, the three switches can include rigidisation switch 324-1 for the rigidised position, launch switch 324-2 for launch position and release switch 324-3 for release position.

[0052] In an exemplary embodiment, the indication switch 300 can include beryllium copper (Be-Cu) leaf spring 326 electrically coupled to the electrical terminals, where the Be-Cu leaf spring 326 provides force and electrical contact. The GFRP spacer 312 is adapted to isolate the complete rigidisation assembly from the switch assembly, where the wires run from the eyelet 330 and the GFRP spacer 312is adapted to restrict the flow of current passing through the interface

bracket 328 that is coupled to rigidisation assembly. The GFRP spacer 312 is spaced by metallic spacer 332.

[0053] The arrangement of the leaf spring-based indication system with two flexible strips arranged in different planes to establish positive electrical contact between mating parts in case of misalignment. In addition, leaf springs 326 are ingeniously profiled in a curved fashion to resist against the launch acceleration loads.

[0054] FIG. 3C illustrates a schematic on board monitoring of rigidisation preload using strain gauges, in accordance with an embodiment of the present disclosure. The rigidisation levers 206 have a provision for on-orbit preload monitoring using strain gauges 334 as shown in FIG. 3C. The strain gauge 334 is located on lever 206, the strain gauge is adapted to verify if the lever is deformed to the same extent as predicted under a preset load or stress level.

[0055] FIGs. 4A and 4Billustraterealized hardware of rigidisation mechanism held down and released configuration, in accordance with an embodiment of the present disclosure. The realized hardware of rigidisation mechanism in which the three levers 206 are in held down position is shown in FIG. 4A and released configuration is shown in FIG. 4B respectively. The mechanism avoids a separate hold-down mechanism to sustain launch loads by ingenious usage of the self-locking property of worm and worm gears, which thereby reduces complexity and saves electrical resources available.

[0056] Thus, the present invention overcomes the drawbacks, shortcomings, and limitations associated with existing solutions, and provides a mechanism that can be used for large as well as low inertia-based spacecraft as the concept can be scaled up suitably to meet docking requirements. The mechanism is mass and power optimised and reduces launch cost as it uses a single motorised actuator connecting all three levers connected through a tensioned wire loop system for motion transfer. The mechanism has the minimum number of components thereby enhancing the reliability of the mechanism. The position indication is provided using a contact switch-based telemetry system. The proposed system saves additional actuators and hold down mechanism mass of more than three kgs per

docking mechanism as compared to conventional systems. The mass saved may be utilised for the accommodation of an additional payload on spacecraft.

[0057] Further, the rigidisation mechanism acts as a hold down during launch by providing the requisite clamping force to the capture ring and the extension/retraction mechanism as there is no separate hold down mechanism planned to sustain launch loads. This is achieved by ingenious usage of the self-locking property of worm and worm gears, which thereby reduces complexity and helps in the design of compact actuator by amplifying the output torque. The mechanism provides sufficient rigidisation preload to clamp the target interface ring with the chaser interface ring thereby providing requisite composite stiffness after the chaser spacecraft captures and retracts the target spacecraft in orbit. Both the operations are performed by ingenious usage of a dual lever mechanism actuated using a single motorized actuator and capable of performing repeatable operations on the ground and in space.

[0058] FIG. 5A illustrates a schematic view of worm and worm wheel-based spool mechanism, in accordance with an embodiment of the present disclosure. The drive mechanism 222 is shown in FIG. 5B can include a stepper motor 502 with a harmonic gear unit of reduction 1000:1. The motor 502 and gear head unit 504 together have the capability to deliver an output torque of nearly 5Nm at 28V. The stepper motor 502 is chosen as compared to the brushless direct current (BLDC) motor as it is easy to control and has a simpler drive electronics circuit. Also, it can provide the position indication by monitoring the number of steps moved. The output shaft of the gear head 504 is coupled to the worm shaft 508 with a double ‘D’ interface 510 to avoid any relative rotation between the two and provides a further reduction of 24:1.

[0059] The ends of the worm shaft 508 are supported on a set of two angular contact super duplex ball bearings 512. The worm 508 further meshes with the worm gear 504 supported on bearings 506 and connected to the mechanism housing 518 with bearing cap 526. The bearings 506 is configured in the bearing bracket 514 and the stepper motor 502 is mounted on a motor mounting bracket 516 with preloading nut 524. A lock nut 520 coupled to angular contact super

duplex ball bearings 512. The worm gear 504 is provided in the worm gear mandrel. SS-440C is used to fabricate the worm as it has high hardness and wear resistance. Phosphor bronze is fabricating worm gears as it has a low coefficient of friction and corrosion resistance.

[0060] Double envelope duplex worm gear tooth type is designed as it has higher torque transmission capacity surface contact area, less backlash, more life, and high shock load resistance. The worm gear is coupled to a wire rope pulley to allow for the winding or unwinding of wire during hold down, release and rigidisation operations without any entanglement. Also, wire retainers are provided on each pulley assemblies to avoid losing contact with pulley while slackening. Usage of worm & worm wheel based drive mechanism avoids an additional hold down and release mechanism to retain mechanism in held down condition during launch by ensuring coefficient of friction (μ) $\geq$ tanβ, where β is lead angle of worm & efficiency (ŋ) < 50%.

[0061] It will be apparent to those skilled in the art that the system 200 of the disclosure may be provided using some or all of the mentioned features and components without departing from the scope of the present disclosure. While various embodiments of the present disclosure have been illustrated and described herein, it will be clear that the disclosure is not limited to these embodiments only. Numerous modifications, changes, variations, substitutions, and equivalents will be apparent to those skilled in the art, without departing from the spirit and scope of the disclosure, as described in the claims.

ADVANTAGES OF THE PRESENT INVENTION

[0062] The present invention provides a mechanism that is scalable to larger and has the minimum number of components thereby enhancing the reliability of the mechanism.

[0063] The present invention provides a system with position indication provided using a contact switch-based telemetry system.

[0064] The present invention provides a system that saves additional actuators and hold down mechanism mass.

[0065] The present invention provides a system having rigidisation mechanism that acts as a hold down during launch by providing the requisite clamping force to the capture ring and the extension/retraction mechanism as there is no separate hold down mechanism planned to sustain launch loads. This is achieved by ingenious usage of the self-locking property of worm and worm gears which thereby reduces complexity and helps in the design of compact actuator by amplifying the output torque.

[0066] The present invention provides a mechanism that provides sufficient rigidisation preload to clamp target interface ring with the chaser interface ring thereby providing requisite composite stiffness after chaser spacecraft captures and retracts the target spacecraft in orbit.

[0067] The present invention provides a system that performs both the operations by ingenious usage of a dual lever mechanism actuated using a single motorized actuator and capable of performing repeatable operations on ground and in space.

We Claim:

1. A system (200) for docking a chaser vehicle to a target vehicle, the system comprising:

   a rigidisation mechanism (204) configured in the chaser vehicle (202-1) and the target vehicle (202-2), the rigidisation mechanism (204) having at least three levers (206) spaced equally located at the periphery of housing, each lever (206) having a primary lever (302-1) in a vertical position and a secondary lever (302-2) in a horizontal position, wherein the primary lever (302-1) comprising:

   a first wedge profile (224-1) located at the top portion defining a rigidisation interface, the rigidisation interface adapted to rigidize, upon docking, the chaser vehicle (202-1) and target vehicle (202-2) together; and

   a second wedge profile (224-2) located at a middle portion defining a launch interface, the launch interface adapted to hold deploying appendages in stowed position during launch;

   a guide pulley (210) configured in the secondary lever (302-2), the guide pulley (210) adapted to guide a wire rope loop (214), the wire rope loop (214) adapted to connect the at least three levers together; and

   a motorized actuator (222) coupled to the guide pulley (210) through the wire rope loop (214), the motorized actuator, upon operation, is adapted to drive the at least three levers to facilitate release, hold down and rigidize operations.

2. The system as claimed in claim 1, wherein the motorized actuator (222) drives the at least three levers (206) to perform hold-down operations during launch by providing the requisite clamping force to hold a capture ring (226) of the chaser vehicle (202-1).

3. The system as claimed in claim 1, wherein the motorized actuator (222) drives the at least three levers (206) to perform rigidize operations by providing suitable preload to provide adequate composite stiffness for controlling both the chaser vehicle (202-1) and target vehicle (202-2) together.

4. The system as claimed in claim 1, wherein the motorized actuator (222) drives the at least three levers (206) to perform release operations by releasing the capture ring (226) of the chaser vehicle.

5. The system as claimed in claim 1, wherein the rigidisation mechanism (204) comprises a strain gauge (334) located on the primary lever (302-1), the strain gauge adapted to monitor the rigidisation preload.

6. The system as claimed in claim 1, wherein at least three levers (206) comprise leaf spring-based switches that comprise rigidisation switch (324-1) for rigidised operation, launch switch (324-2) for hold-down operation and release switch (324-3) for release operation.

7. The system as claimed in claim 6, wherein the leaf springs (326) with two flexible strips arranged in different planes establish positive electrical contact between mating parts in case of misalignment and are ingeniously profiled in a curved fashion to resist against the launch acceleration loads.

8. The system as claimed in claim 1, wherein the motorized actuator (222) is a non-back drivable actuator, the non-back drivable actuator is a worm and worm gear-based drive mechanism, which helps in retaining tension in the wire rope loop thereby maintaining requisite preload against launch acceleration.

9. The system as claimed in claim 1, wherein the motorized actuator (222) comprises worm gear that is coupled to the guide pulley (210) through the wire rope loop (214) to allow for the winding or unwinding of the wire rope loop (214) during hold-down, release and rigidisation operations without any entanglement

10. The system as claimed in claim 1, wherein the rigidisation mechanism (204) comprises loaded hard stopper (218) adapted to limit extreme movement of the at least three levers (206).

For Indian Space Research Organisation

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ABSTRACT

DUAL-LEVER RIGIDISATION MECHANISM WITH A SELF-HOLD DOWN FEATURE FOR AUTONOMOUS DOCKING OF SPACECRAFT

The present disclosure relates to a system (200) for docking a chaser vehicle to a target vehicle, the system includes a rigidisation mechanism (204) having at least three levers (206), each lever (206) having a primary lever (302-1) that includes a first wedge profile (224-1) located at top portion defining a rigidisation interface, and a second wedge profile (224-2) located at a middle portion defining a launch interface. A guide pulley (210) configured in the secondary lever (302-2) and adapted to guide a wire rope loop (214) to connect the at least three levers together. A motorized actuator (222) coupled to the guide pulley (210) through the wire rope loop (214), the motorized actuator, upon operation, adapted to drive the at least three levers to facilitate release, hold-down and rigidize operations.

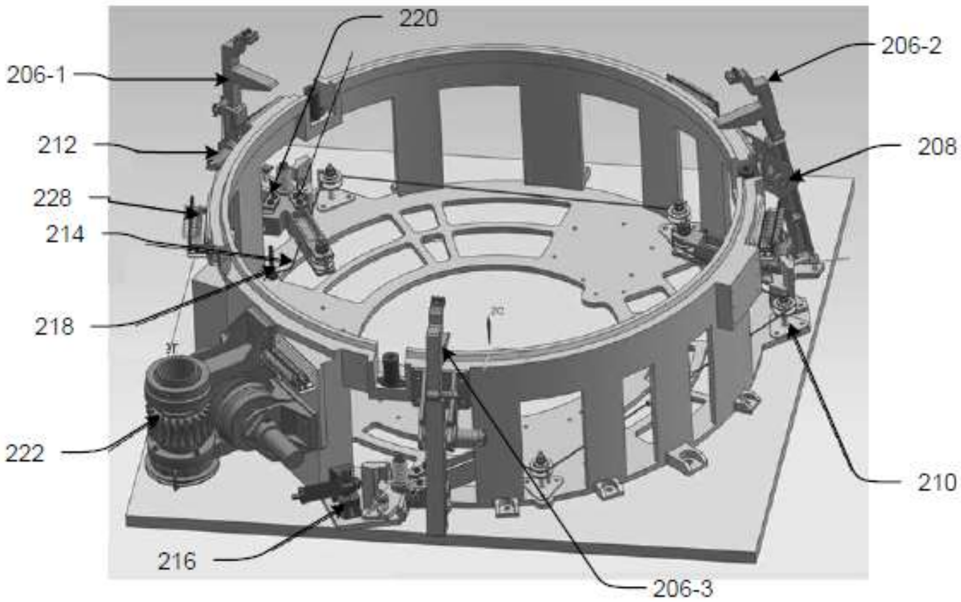

FIG. 2D

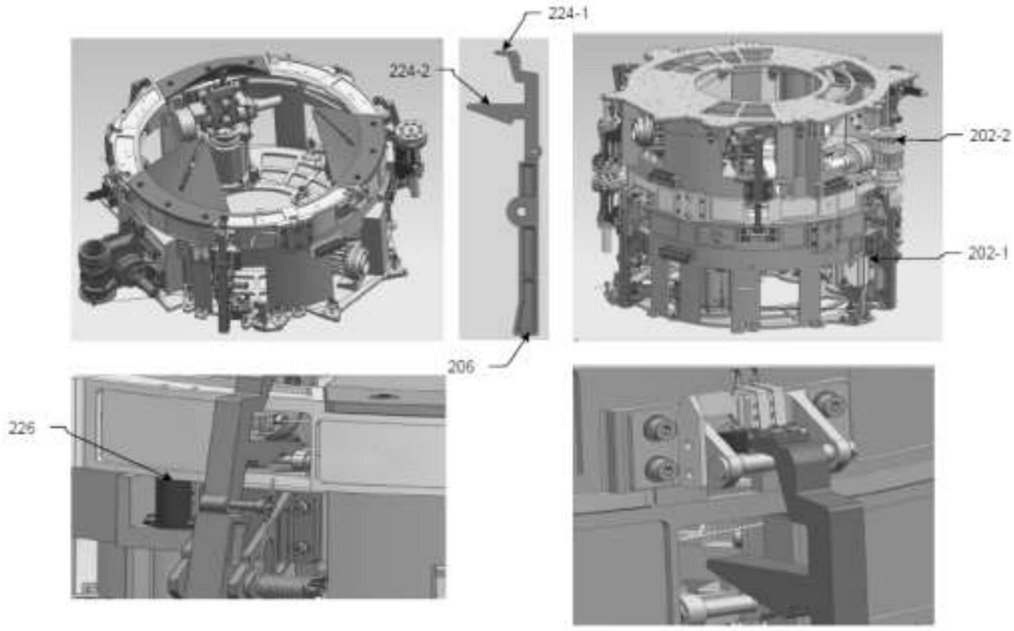

FIG. 2E

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